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A novel all optical reversible 4 × 2 encoder based on photonic crystals

Mahdi Hassangholizadeh-Kashtiban [a], Reza Sabbaghi-Nadooshan [b,*], Hamed Alipour-Banaei [c]

[a] Department of Electronics, Arak Branch, Islamic Azad University, Arak, Iran
[b] Department of Electronics, Central Tehran Branch, Islamic Azad University, Tehran, Iran
[c] Department of Electronics, Tabriz Branch, Islamic Azad University, Tabriz, Iran

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ABSTRACT

In this paper, we designed a reversible all-optical 4 × 2 encoder using a two-dimensional square lattice rods in air photonic crystal with nonlinear refractive index. Our main structure composed of seven vertical waveguide and two elliptical rings. Plane Wave Expansion (PWE) and Finite Difference Time Domain (FDTD) methods are used to calculate band structure and wave propagation in the structure, respectively. Reversible encoder is designed within small size and has ability to be integrated in optical integrated circuits. This reversible encoder is the first optical encoder based on photonic crystals. The results show that our structure could act as an optical reversible encoder.

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1. Introduction

Optical Logic Gates are fundamental constituent of digital data processing systems. However, using traditional logic gates causes loss of energy. Using the laws of physics we know that total amount of energy in any isolated system remains constant, and cannot be created or destroyed, although it may change forms. Therefore, the power which loose at systems based on traditional logical gates. Release in the form of heat energy. That it brings problems for the information processing systems. But since in information processing systems loosing energy means destroying information, then would face destroying information. Best solution for preventing this issue is use of reversible logical gates. Reversible gates are new advanced version of traditional gates where a one by one mapping is established between an input vector and an output vector of gate. Hence, in information processing systems which are designed by reversible optical gates input vector can be reconstructed of input vector in an exclusive way and vice versa. Therefore, these gates open new window for researchers that they can design processing information systems where data loss and heat loss reaches its minimum [1–3]. In reversible gates consonant inputs are called ancilla input and outputs are considered that have been created just for mapping as a secondary output are called garbage. But it should note that those outputs that are created as input in the output are not garbage [4]. Reversible gates have many applications in the field of quantum computing, quantum cellular automata, optical computing and Nano computing [5–14].

Designing of reversible optical gates attracted attention of researchers in recent years. Because the growing trend of ever smaller information processing systems and the increasing need of more bandwidth and high speed in these systems, maybe in the near future, information processing systems no longer can be created that would response these needs. So, we must look for a replacement for these systems, that components and optical systems are the best option for this purpose. Optical information processing systems can provide broad bandwidth and high data transfer rate to with a low cost. Different optical reversible gates are designed such as Mach-Zehnder interferometer based logic gate, Peres gate, modified Fredkin gate and reversible binary adder [15–18]. Although, reversible optical gates already are designed to increase good performance in terms of speed, power consumption and high switching speed, to have all these gates are in addition to that they are more limited to mach-zehnders, they have a great size that meets their capacity for integration of optical integrated circuits to challenge. With the introduction of photonic crystal structures in the last decades, opened new world of photonics science to researchers so that they could design optical devices on a smaller scale (Nano level) that have usability in the integrated optical circuit. Photonic Crystal (PhC) structures are periodic layers of dielectric materials, which due to being periodic divided into three types: (1) one dimension (2) two dimensional and (3) three dimensions. These structures due to being periodic have unique property named optical band gap that separates them from other structures. Band gap is a wavelength range in which no electromagnetic

* Corresponding author. Tel.: +98 2144600047; fax: +98 2144600063.
E-mail address: r_sabbaghi@iauctb.ac.ir (R. Sabbaghi-Nadooshan).

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wave can propagate in photonic crystal structure. We can create a defect in photonic crystal structure in order to disrupt unrighteousness periodic structure and pass the specific wavelengths within the band gap of the structure. Then, there are designed a lot of optical devices using photonic crystals including Optical Demultiplexers, Optical Filters, Optical Switches, Optical Memories and Optical Modulators [19–29]. Optical logical gates such as: OR, NOR, NAND, XNOR and AND are designed based upon photonic Crystals [30–32]. As well as the optical logic gates based on photonic crystals with nonlinear refractive index are also designed [33,34]. Refractive index of photonic crystal structures in nonlinear photonic crystal change with changing power of incident light which illuminating into the photonic crystal structure. Therefore, hence, we can increase refractive index with increasing input light power that it causes a shift in the band gap. We can design all-optical devices using photonic crystals with nonlinear refractive index that have integration ability for optical integrated circuits.

In this work, we are designed a reversible all-optical 4×2 encoder using a two-dimensional photonic crystal with nonlinear refractive index. Reversible encoder is designed within small size and has ability to be integrated in optical integrated circuits. As well as, for the best of our knowledge this reversible encoder is the first optical encoder based on photonic crystals that is published in the articles so for. Encoders can be useful in creating optical mouse, all-optical logic controllers (PLC) and with combination with other logic gates used to create all-optical systems. To study the light propagation within the structure of the method we have used of 2D finite deference time domain method. As well as, to calculate the band gap of the structure we have used of plane wave expansion method.

The rest of the paper is organized as follow: in Section 2 the designing procedure is discussed. In Section 3, the proposed design is described. Section 4 discussed the results of the simulations and the output properties of the proposed encoder. Finally, Section 5 concluded the paper.

2. Designing procedure

In this paper our designing procedure had been subtended of three main steps: (1) designing a basic platform PhC structure by using gap-map Diagrams (2) designing an all-optical switch based an elliptical resonant ring (3) designing all-optical 4×2 reversible encoder by using elliptical rings and vertical waveguides. In the first step of our designing procedure we mainly focus on extracting suitable band structure by investigating gap-map analyze. In order to calculate PBG (Photonic Band Gap) and obtaining gap-map diagram numerical methods are the best solution. PWE (Plane Wave Expansion) is one of numerical methods, which is used for extracting PBG by calculating Maxwell equation in frequency domain. In second step we will design an all-optical switch by using elliptical resonant ring. Finally in the third step we are going to design our proposed 4×2 reversible encoder structure by creating elliptical rings and vertical waveguides inside the basic plat form photonic crystal structure. In order to investigate light behavior in our proposed structure we used Finite Deference Time Domain (FDTD) method. Also effective index method had been used to reduce 3D simulation to 2D simulation ones with neglible errors. Our device is surrounded by nonlinear Perfectly Matched Layers (with width equal to 500 nm) for simulate the light wave behavior out of the structure.

3. The proposed structure

In order to design our proposed structure we used 26×23 square lattice photonic crystal composed of cylindrical dielectric rods in air. Our structure includes three basic parameters: a, r and n which are lattice constant (distance between center of two adjacent rods), radius of dielectric rods and refractive index of structure, respectively. In this work effective refractive index of rods is $n = 3.47$ and also rods have nonlinear coefficient of $n^2 = 3.3 \times 10 - 13\,(\mathrm{cm}^2/\mathrm{W})$. In order to choose the proper values for r and a, we used gap-map diagram of our basic platform structure for different value of r/a ratio with constant refractive index. This Gap-map diagram is illustrated in Fig. 1. Fig. 1 shows gap variation versus r/a ratio, one can see with increasing value of r/a ratio PBG width will be decrease. Since 2D PhC rod in air structures have dominance PBG in TM mode, so we had done all of our simulations in TM mode. In order to have band gap with suitable width we choose following value for radius of rods and lattice constant: $r = 106$ nm and $a = 590$ nm. Fig. 2 shows band structure of 2D PhC with above mentioned parameters. In Fig. 2 the reign with dark blue color represent the band gaps of structure. The band gap is in the range of $0.3 < a/\lambda < 0.48$ which is equal to $1222\,\mathrm{nm} < \lambda < 1966\,\mathrm{nm}$.

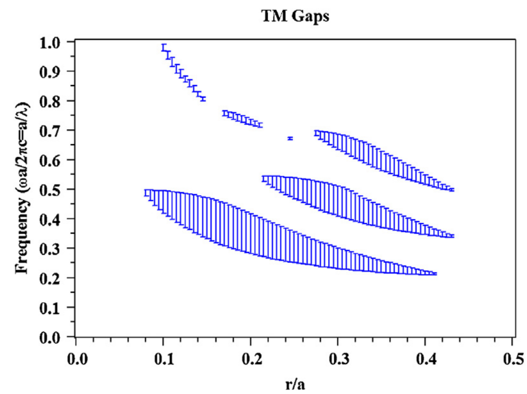

Fig. 1. Gap-map diagram of proposed platform photonic crystal structure.

3.1. Switch design

Our proposed switch structure consists of three main parts: one line defect as input waveguide (the lower one), one line defect as output waveguide (the upper one) and elliptical resonant ring as switching mechanism, which is located between two waveguides. The schematic diagram of our proposed switch is shown in Fig. 3 with elliptical ring. As shown from Fig. 3 elliptical ring structure composed of two individual ellipses and each ellipse consist of three basic parameter miner radius, major radius and dielectric radius. In Fig. 3 the value of inner ellipses parameters

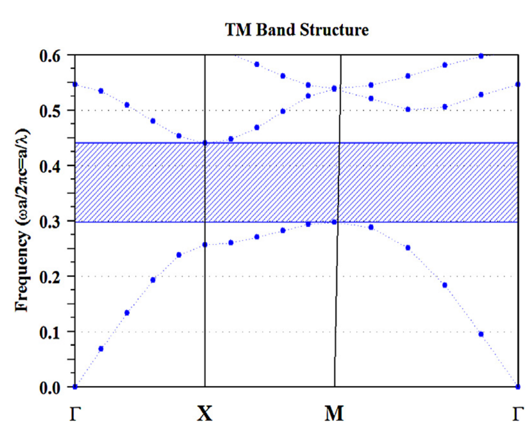

Fig. 2. band gap of our proposed photonic crystal structure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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